NAVAL SUBMARINE MEDICAL RESEARCH LABORATORY

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REPORT NUMBER 1063

TEMPORARY AUDITORY-THRESHOLD SHIFTS INDUCED BY TWENTY-FIVE-MINUTE CONTINUOUS EXPOSURES TO INTENSE TONES IN WATER

by

Paul F. Smith and John Wojtowicz

Naval Medical Research and Development Command
Research Work Unit M0096.002-1047

Released by:

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NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
Research Project 63706N M0096 M0096.002 1047

Approved and Released by

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SUMMARY PAGE

THE PROBLEM

To develop a data base upon which to establish hearing-conservation standards for Navy divers exposed to noise emanating from hand-held tools.

FINDINGS

Bare-headed divers exposed in water for twenty-five minutes to continuous tones at sound pressure levels between 141 and 165 decibels above 20 micropascal incurred temporary auditory-threshold shifts of 23 to 55 dB that required twenty-four hours to in excess of fifty hours for recovery. Divers routinely using certain hand-held tools for periods as short as twenty-five minutes a day may incur substantial noise-induced hearing loss.

APPLICATION

The findings contribute to the establishment of a hearing-conservation standard for Navy divers exposed to intense noise in water.

ADMINISTRATIVE INFORMATION

This research was carried out under Naval Medical Research and Development Command Work Unit 63706N M0096 M0096.002 1047, "Development of an interim hearing conservation standard for hand-held underwater tools." It was submitted for review on 12 July 1985, approved for release on 25 September 1985, and designated as NSMRL Report Number 1063.

ABSTRACT

Four bare-headed divers were exposed for twenty-five minutes to continuous tones in water at frequencies of 700, 1400, and 5600 hertz at estimated sound pressure levels between 153 and 165 decibels (dB) above 20 micropascal. Subsequent analyses revealed that the eight ears involved were actually exposed to average sound pressure levels between 143.1 and 165.1 dB. These exposure levels are comparable to those to which divers may be exposed while using some underwater hand-held tools. Temporary auditory-threshold shifts (TTS) were measured from two minutes to five minutes after the exposure terminated. TTS at two minutes post-exposure was between 23 and 55 dB and recovery times varied from twenty-four hours to more than fifty hours depending on exposure conditions. Nonauditory effects including middle-ear sensations and a reddened ear-drum were also observed. The results indicate that several hand-held tools now in use by military and civilian divers are extremely hazardous to hearing. The results also support the theory that the dynamic range of the water-immersed ear is smaller than the dynamic range of the ear in air.

INTRODUCTION

Navy divers are exposed in water to intense noise that originates from a variety of sources including active sonar systems and various hand-held tools. Noise levels produced by several tools were measured by the Naval Coastal Systems Center and those data have been made available to this laboratory (Smith, 1983). Those data show that noise levels from a Partek High Pressure Water Cleaning Tool and the Daedalean Concaver Hand Gun were between 141 and 146 decibels (dB) above 20 micropascal[1] in the octave band centered at 4000 hertz (Hz). A Stanley Rock Drill, SK-58 produced levels of 155 dB in the 1250 to 2000 Hz frequency region. Overall noise levels in the 1000 to 20,000 Hz region were somewhat higher, ranging up to about 160 dB for some of the tools. The noise levels just cited however, are "average" levels and are based on a large number of measurements for various tools in different operating modes. The individual samples of noise levels obtained ranged from about 124 dB to 164 dB.

Very few data are available on the effects of intense water-borne noise on hearing, yet many divers use noisy tools routinely. Montague and Strickland (1961) found that, of 23 bare-headed divers, all would tolerate 160 dB tone pulses at 1500 Hz indefinitely, and, depending somewhat on the orientation of the diver to the sound source, about 75 percent of the divers would tolerate sound pressure levels of between 170 to 173 dB. Smith et al. (1970) found that the sound pressure level of 3500 Hz tones pulses had to be about 68 dB higher than tones in air in order to produce equivalent amounts of temporary auditory-threshold shifts (TTS) in breath-holding swimmers.

In an effort to obtain sufficient data upon which to construct a hearing-conservation standard for wet-suited divers using hand-held tools, a series of experiments on TTS induced by water-borne stimuli in the 500 Hz to 8000 Hz frequency region is being done. The initial experiment was aborted when very severe and long-lasting TTS were obtained in four divers. This report details that experiment.

METHOD

The experimental design called for three groups of eight divers (twenty-four subjects) to be tested under a three-factor mixed design in which the independent variables were exposure frequency, exposure sound pressure level, and medium (air or water). This section describes the method used to collect data on four divers prior to the suspension of data collection.

<u>Subjects</u>. The subjects in this experiment were four young Navy divers who had normal hearing levels. One had a hearing level of 25 dB in his right ear at 3000 Hz but otherwise, none had hearing levels in excess of 15 dB in either ear at any frequency.

Apparatus. Three sets of apparatus were used in the experiment:

Audiometric and threshold measurement apparatus: Audiometry was accomplished using a Grason-Stadler 1703B recording audiometer. Subjects were tested in an Eckel Industries Eckoustic audiometric booth. Ambient levels within the booth were measured with a Bruel & Kjaer type 2205 sound level meter and a B&K type 1613 octave filter set. Those levels were sufficiently low that masking did not occur at the frequencies employed, but low-frequency noise was present that was distracting to the subjects. Pre-exposure and post-exposure single-frequency/single-ear tests were also administered using a Hewlett-Packard model 204C oscillator, a Grason-Stadler model 829E electronic switch, a Grason-Stadler model E3262A recording attenuator, and the same response switch and earphone as were used for the audiometry.

Noise-exposure apparatus (air): A Hewlett-Packard model 3320B frequency synthesizer generated the exposure tones. These were passed through a Hewlett-Packard decade attenuator to deliver fatiguing tones to the subject via a TDH-39 earphone. Exposure levels were measured with the B&K sound level meter through a B&K model 158 audiometer calibrator. Exposure and test frequencies were measured with a Hewlett-Packard model 5512A electronic counter. A Ballantine Laboratories model 643 AC voltmeter was used to monitor exposure voltages at the earphone.

Noise-exposure apparatus (water): A Honeywell type HX-188 transducer was used to deliver 700 and 1400 Hz tones. A USRD type F56 transducer was used to deliver 5600 Hz tones. These devices were driven by an Industries Inc. 1000W amplifier. A USRD type F50 hydrophone and a separate Ballantine AC voltmeter in parallel with a spectrum analyzer were used for underwater sound field calibrations. Since the presence of the diver and his exhaust bubbles distorted the sound field it was not possible to measure exposure levels during the exposure period. Exposure sound levels were established and the output settings and output voltages of the driving amplifier were recorded. These data were used to create the exposure levels during the experiment. Calibrations were done with the F50 hydrophone located at the position of the center of the diver's head.

Exposure environments. Noise doses in air were delivered through a TDH-39 earphone to one ear only. Subjects were seated outside of, but close to the audiometric booth. Noise doses in water were delivered in a reverberant field in a 20' by 60' pool that is 35' deep. Subjects were at a depth of 20 feet. The center of the subject's head was approximately 18 inches from the face of each transducer with the subject facing between the transducers which were about 36 inches apart. Consequently, 700 Hz and 1400 Hz tones came from the HX-188 transducer that was to

the subjects' left, and the 5600 Hz tone came from the F-56 that was to the subjects' right. In water, subjects used open-circuit self-contained breathing apparatus. Three wore wet suits and face masks but no hoods, and one subject wore a dry suit with face mask but no hood.

Hearing tests. Two test procedures were used to measure hearing thresholds. One was conventional recording audiometry in which thresholds were measured at 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The frequency changed every 30 seconds.

The second procedure was a self-recording test during which thresholds were measured at a fixed frequency (the test frequency) for an indefinite time period. This test, when administered before noise exposures is called the pre-exposure or baseline test, and when administered after noise exposure, it is called the post-exposure or TTS test. This test provided the primary data of the experiment. It was always administered to a single ear designated the test ear. Temporary threshold shifts were computed by subtracting baseline results from post-exposure test results.

The magnitude of TTS at various post-exposure times, the trends of growth of TTS with increasing intensity, and the slopes of recovery curves were the dependent variables. TTS was computed at the test frequency for the test ear based upon the results of the single-frequency test. For individual subjects the test frequency was about 1/2 octave above the exposure frequency. For the exposure frequencies of 700, 1400, and 5600 Hz, the test frequencies were 1000, 2000, and 8000 Hz, respectively.

Procedure. Prior to the experiment, all subjects were briefed on the purpose and nature of the experiment and consent forms were administered. Subjects were then tested audiometrically. Final subject selection and assignment to experimental conditions was made on the basis of this test. For each subject a test ear and test frequency was selected which was used for that subject throughout the experiment. That was the ear and frequency used for baseline and TTS tests, and the ear to which fatiguing tones were delivered for noise exposures in air. The subjects were then briefed on the procedures and given training on the fixed-frequency test.

Each subject was tested individually. Prior to each noise exposure in water, a complete audiogram was taken on both ears. Then, a baseline measurement was made at the test frequency on that subject's test ear. Next, the subject dove to a diving stage located at a depth of 20 feet. Each subject was tended by a second diver at the surface with whom the subject could communicate by hand line. When the subject was in place and ready (seated and stable) the subject signalled the surface tender. Then, the exposure tone was turned on at one of three

predetermined sound pressure levels. Twenty-five minutes later, the tone was turned off and the subject came to the surface, left the water, removed breathing apparatus, face mask, and weight belt, dried off, and entered the audiometric booth where the experimenter placed the headset on the subject's head after insuring that no water remained in the ears. Then the TTS test at the same frequency and on the same ear as used for the baseline test was run until five minutes or so after the exposure tone was turned off. Immediately following that, the subject was administered another complete audiogram on both ears, test ear first. Subsidiary TTSs were computed at 500 to 8000 Hz for both the test and contralateral ears by subtracting preexposure audiometric results from post-exposure audiometric results.

The procedure for exposures in air was the same as for the exposures in water except that the noise dose was delivered monaurally by earphone.

It was essential that the times between the cessation of the exposure tone and, 1) the beginning of the TTS test, and 2) the beginning of the audiogram be recorded precisely. Because of the splendid cooperation of the subjects (who also served as the surface crew), it was possible for all divers to reach the audiometric booth with heads reasonably dry within 90 to 100 seconds after the fatiguing tone was turned off. For all hearing tests and for noise exposures in air, the headsets were placed on the subject by the test administrator.

Post-exposure results were evaluated immediately. If TTS in excess of 5 dB was present at any frequency in either ear the subject was retested. If following such a retest a subject still exhibited a threshold shift greater than 5 dB, that subject was rescheduled for an additional test one to three hours later.

The first of three planned exposures for each diver produced larger amounts of TTS than were expected. The collection of further noise-exposure data was suspended pending an examination of the sound field to which the divers were exposed. Since it was impractical to measure sound levels while the subjects were in the water the possibility existed that through sound-reinforcement or a similar mechanism, the sound levels to which the divers were actually exposed were higher than the levels measured with the diver not present. In order to ensure that such calibration errors were not responsible for the unexpectedly large threshold shifts observed, the procedure described below was carried out.

Sound levels were recreated at the levels to which the divers were intended to be exposed and spectra were recorded. These measurements were made with an F50 hydrophone located at the position of the center of the divers head as during the initial calibrations. The output settings and output voltages

of the driving amplifier were recorded. Then, two F-50s were placed 10 inches apart (five inches to either side of the center of the divers' head positions) approximately one to two inches from the position of the divers' ears and spectra again recorded. Next, the level at the F-50 which was near the position of the divers' left ears was adjusted to 104 dB and the output settings and output voltages of the driving amplifier were again recorded. Then, a diver was positioned between the F50s and measurements were made of the influence of the divers on the sound field. This sound field mapping was done using two additional divers. These data were then used to estimate the actual exposure conditions for each of the four subjects.

RESULTS

Since each subject was assigned to a different experimental condition, the results are presented here for each individual. Two subjects were exposed at 1400 Hz but at different sound pressure levels. The results are shown in Figure 1 in which each panel label (A, B, C, D) refers to a specific diver. All subjects exhibited classic TTS patterns in that the maximum threshold shift occurred at a frequency 1/2 octave above the exposure frequency and all eight ears exhibited recovery that was generally linear in log time. For the underwater exposures, there was a spread of the threshold shift to higher frequencies, but, except in one definite case, there was little or no involvement at frequencies below the exposure frequency. The exceptional case, however, is not contrary to what would be expected for the noise dose that diver apparently received.

Diver A: The right ear of this diver was exposed to 5600 Hz at 100 dB in air for twenty-five minutes. He exhibited a TTS at two minutes after the exposure (TTS_2) of 5 to 6 dB at 8000 Hz and appeared to have recovered to pre-exposure levels by the end of the single-frequency TTS test at six minutes post-exposure time. Subsequent testing on the post-exposure audiogram confirmed this recovery.

The following day diver A was exposed in water to a 5600 tone at 165 dB for twenty-five minutes (see panel A of Figure 1). At the end of the exposure, his test ear exhibited TTS at 8000 Hz of 36, 34, and 32 dB at two, three, and four minutes after the exposure. Subsequent results from the audiometric test showed for the test ear TTS_{11} of 30 dB and TTS at about two hours after the exposure of 17 dB. For the contralateral ear, diver A showed a TTS_{15} of 25 dB and at two hours, a TTS of 19 dB. Recovery proceeded slowly and full recovery had not occurred at twenty-four hours. At that time TTS at 8000 Hz was 15 and 12 dB in his right and left ears respectively. At 48 hours this subject's data are equivocal. He exhibited depressed hearing in his right ear of up to 25 dB at frequencies of 4000 to 8000 Hz and 28 dB at 6000 Hz in his left ear. Diver A had a slight cold at the time and these latter results may have been

due to transient congestion at the time the test was done. A subsequent audiogram performed from two to three hours later in an ENT clinic by an audiologist not involved in the study showed that diver A had a 5 dB loss at 8000 Hz in his left ear compared to his hearing level measured in 1977. There were no changes in his hearing at any frequency between 500 Hz and 6000 Hz in either ear since the time of the latest audiogram in his health record which was done in December 1982. The subject appears to have recovered completely from the exposure.

Subsequent sound-field mapping revealed that this diver's test ear had been exposed to an average sound pressure level of 165.1 dB with the sound level varying between 157.6 and 170.8 dB as a result of the influence of the diver and his exhaust bubbles. His contralateral ear was exposed at an average level of 153.2 dB with a range of 139.8 dB to 165.4 dB.

Other symptoms: Diver A reported that, if his face was down during the exposure, his head vibrated. He believed that the vibration was due to the effects of the sound on his exhaust bubbles. When he raised his head the effect was reduced. He reported a tickling sensation in his middle ear such as is frequently reported for exposure levels in air close to the threshold of aural pain (120 to 140 dB).

Diver B: The right ear of this subject was exposed in air for twenty-five minutes to a 1400 Hz tone at 95 dB. At 2000 Hz TTS_2, TTS_3, and TTS_4 were 5, 4, and 0 dB, respectively. The subsequent audiometric test showed a TTS_6 of 7 dB but the next audiogram performed about one hour later showed a -7 dB shift. It is believed that recovery had occurred within ten minutes.

The following day, diver B was exposed in water to 1400 Hz at 153 dB (see panel B of Figure 1). His selected test ear was farther from the transducer than his contralateral ear. The test ear (at 2000 Hz) exhibited TTS_2, TTS_3, and TTS_4 of 23, 20, and 19 dB and TTS_{110} was 9 dB. Full recovery of the test ear had occurred by 24 hours post-exposure time. His contralateral ear was first measured at 12 minutes post-exposure time and showed a TTS of 47 dB at 2000 Hz. Extrapolating back from the recovery curve for this ear indicates that TTS_2 must have been about 55 dB. This ear had not recovered completely by 48 hours after the exposure. The subsequent test at the ENT clinic showed a 15 dB loss at 2000 Hz and a 10 dB loss at 3000 Hz from an audiogram performed in September 1983.

Sound mapping revealed that diver B's test ear had been exposed at an average sound pressure level of 143.7 dB (range 129.7 to 151 dB) and that his contralateral ear was exposed at a average level of 151.3 dB (range 146.3 to 156.1 dB). Furthermore, harmonics at 2800 Hz and 4200 Hz may have produced TTS at 4000 Hz and 6000 Hz.

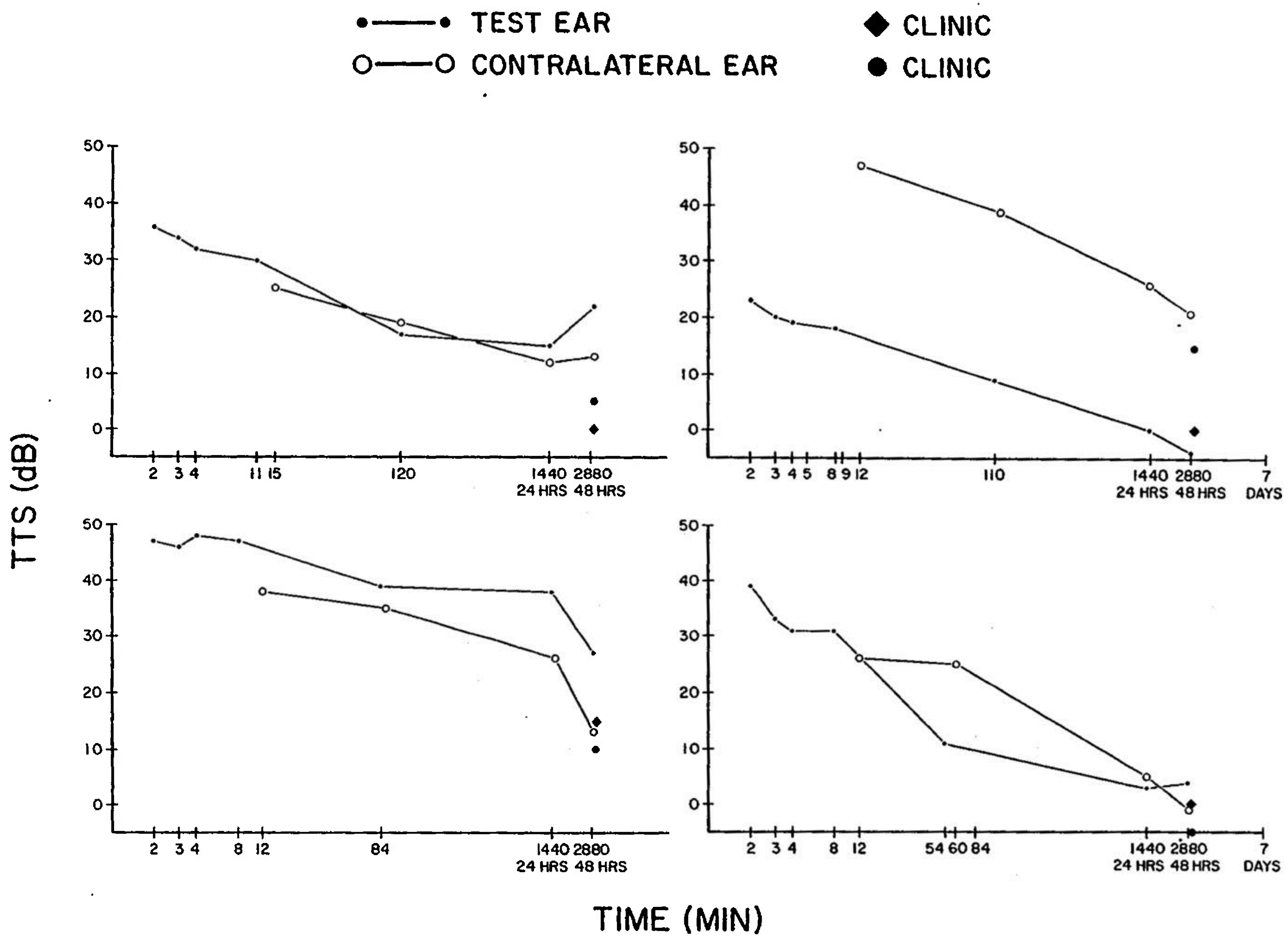

Figure 1. Temporary auditory-threshold shifts for four divers (A, B, C, D) as a function of time following cessation of the exposure. Time is plotted on a logarithmic scale.

Other symptoms: Diver B reported that, following the exposure, everything sounded flat. This may be attributed to threshold shifts of 34 dB, 22 dB, and 11 dB at 3000, 4000, and 6000 Hz in his left ear measured twelve to fifteen minutes post exposure. That ear also suffered about 10 dB TTS at 500 and 1000 Hz. This flatness symptom disappeared subsequently as did the threshold shifts at other than 2000 Hz and 3000 Hz.

Diver C: The left ear of this man was exposed in air to 700 Hz at 95 dB. TTS_1 through TTS_3 showed increasing loss from 24 to 31 dB, with recovery out to TTS_6 (26 dB) being very flat. The audiometric test showed $TTS_{6.2}$ to be 20 dB and one minute later TTS was 17 dB. TTS_{66} was 8 dB. Recovery at the 1000 Hz test frequency was complete (1 dB) at twenty-four hours post-exposure. This twenty-four-hour audiogram was the pre-exposure audiogram for the exposure in water. It shows an inexplicable change from his previous tests of from 12 to 27 dB in his left ear at frequencies above 2000 Hz and a 12 and 10 dB loss in his non-exposed ear at 4000 and 8000 Hz, respectively. Consequently, his post-exposure audiogram for the in-water exposure were compared against both of his pre-exposure results.

Diver C was exposed in water to 700 Hz at 160 dB for twenty-five minutes (panel C of Figure 1). His test ear was closer to the transducer than his contralateral ear was. TTS at 2, 3, and 4 minutes post exposure was 47, 46, and 48 dB respectively. TTS was still 47 dB at eight minutes after the exposure and at 47 dB 80 minutes post-exposure. At 24 hours TTS in the test ear was still 38 dB. At 48 hours TTS was between 24 and 27 dB in the test ear. The subsequent test at the ENT clinic showed a loss of 15 dB in that ear at 1000 Hz from the latest audiogram in his health record which was performed in May 1983. The results for his contralateral ear were similar but of lesser magnitude. For that ear, TTS_{12} was 38 dB and TTS at 48 Hours was 13 dB. The clinic test showed a 10 dB loss from the test of the previous year.

Post-experiment sound mapping showed that this diver was exposed to an average level of 160.9 dB (range 152.8 to 167.8 dB) at the test ear and to 143.1 dB (137.6 to 152.8 dB) at the contralateral ear.

Other symptoms: Diver C reported low-tone ringing in his ears following his exposure in water. He said that when the sound was on, his head vibrated (felt like his brain was vibrating) when his head was down. This effect lessened when he raised his head. Forty-eight hours after the exposure, diver C still reported tinnitus.

Diver D: Diver D's left ear was exposed at 1400 Hz to 90 dB. TTS_2 was 6 dB and recovery was complete by four minutes after the exposure although the subsequent audiometric test showed a TTS_8 of 5 dB. The next test on this man about 35

minutes after the exposure showed a -2 dB shift. It is believed that recovery was complete at four minutes after the exposure.

The following day, this man was exposed in water to 1400 Hz at 163 dB, with his test ear being the closest to the transducer (panel D, Figure 1). His TTS at 2, 3, and 4 dB were 39, 33, and 31 dB, respectively; TTS_8 was 18 dB; TTS_{108} was 11 dB. Recovery was complete at twenty four hours (3 dB). The results for the contralateral ear were similar. At the twenty-four-hour test this ear exhibited a threshold shift of 5 dB. The 48 hour audiogram showed a 4 dB shift in the test ear and the clinical evaluation showed no change in this man's hearing at 2000 Hz in either ear since March 1983.

Sound mapping revealed that diver D's test ear had been exposed at an average sound pressure level of 161.3 dB (range 156.3 to 166.1dB) and that his contralateral ear was exposed at a average level of 153.7 dB (range 149.7 to 161.0 dB)

Other symptoms: Diver D had a bloody left ear (Teed class 2-3) a few hours after the exposure and pain in both ears (right ear most severe) for at least two days following the exposure. He reported that he felt as if his eyes were watering during the exposure, but could not be sure that it was not due to his face being wet. Forty-eight hours after the exposure, the left ear had recovered but still showed signs of inflammation about some blood vessels. By one week post-exposure, the symptoms (pain and redness) were gone. Diver D had no recent incident of aural barotrauma that could account for the Teed ear.

Follow-up testing in the ENT clinic accomplished about two months after the noise exposure showed that none of the divers had incurred any permanent threshold shifts. All other symptoms of excessive noise exposure had long since disappeared.

DISCUSSION

Since there were only four subjects in this experiment and each one was exposed under different conditions, these results must be interpreted cautiously. For example, it is a common experience in studies of temporary auditory-threshold shift that some subjects are more susceptible to noise-induced TTS than others. Some, referred to as "tough eared" incur relatively small amounts of TTS and recover rather rapidly. Others incur relatively large amounts of TTS and/or recover slowly. From the results of the exposures administered in air divers A and D may be relatively "tough-eared" and B and C "tender-eared".

This concept may have relevance in the comparison of the results for the two subjects who were exposed to 1400 Hz. Divers B and D were both exposed to 1400 Hz in water. Diver B was exposed at 151.3 dB, incurred a very large TTS with involvement at all frequencies tested including frequencies

below the exposure frequency, and at 50 hours after the exposure still had about a 15 to 21 dB TTS. Diver D was exposed to 1400 Hz at 161.3 dB (ten dB higher than B), incurred a substantial TTS_2, which was nevertheless perhaps 15 dB smaller than that incurred by B, and was within three to five dB of complete recovery 24 hours after the exposure. On the other hand, D exhibited nonauditory symptoms that indicate his exposure was more physically damaging than B's exposure. This result is convincing evidence that hearing-conservation standards for divers need to be based on data from a large number of subjects.

These data do not point to a noise level at which divers may safely be exposed, but they do indicate that exposures to similar conditions ought to be avoided. The highest average sound pressure level to which an ear was exposed in this experiment was 165.1 dB. Exposure frequency was 5600 Hz and TTS_2 at 8000 Hz was 36 dB. No known tool with the possible exception of the Flow Industries (NCEL) high-pressure water tool produces sustained noise at that level. Two ears were exposed to average sound pressure levels of 160.9 and 161.3 dB at frequencies of 700 Hz and 1400 Hz, respectively, levels that are not unusual for Cavijet and Flow Industries jet cleaning tools. TTS_2s were about 50 dB for both ears. Three ears were exposed at 151.3 to 153.7 dB (three different frequencies), which is not uncommon for the Stanley SK-58 and HD-20 rock drills and is sometimes approached by the Stanley IW-20 impact wrench. TTS_2s ranged from 30 to 55 dB. The remaining two ears were exposed at sound pressure levels of 143.1 and 143.7 dB (700 Hz and 1400 Hz, respectively). TTS_2s were 44 dB for a diver exposed at 700 Hz and 23 dB for a diver exposed at 1400 Hz. These levels are almost always produced by all known jet cleaning tools and at least occasionally by all other measured hand-held tools.

Arguments can be made that these comparisons are specious since most tools produce broad-band noise, hence much lower spectrum levels, and this experiment used pure-tone stimuli. However, the current hearing-conservation standards in use throughout the Department of Defense and the OSHA regulations do not distinguish between broad-band and narrow-band spectra.

Further arguments can be made that divers can be protected from excessive noise by wearing hoods. Molvaer, et al (1979) measured threshold shifts of only 5 to 10 dB for a wet-suited diver wearing a 5 mm thick neoprene wet-suit hood after a one-hour period of operating a Woma high-pressure water-jet tool. The tool produced a noise level in excess of 140 dB with most of the energy being at 4000 Hz and higher. In a subsequent experiment (Molvaer and Gjestland, 1981) a similarly hooded diver exhibited no TTS following one hour operation of a water-jet tool. However, citing that diver's "completely normal" hearing after a 13-year history of professional diving using noisy tools, Molvaer and Gjestland suggest that that subject has a high resistance to noise. While it is true that wet-suit hoods can provide substantial noise attenuation at

frequencies of 1000 Hz and above, hoods provide little protection below that frequency ((Montague and Strickland, 1961, Smith, 1969). Also, the amount of noise protection afforded by wet-suit hoods is extremely variable, and in some divers it has been found that not more than 15 dB attenuation is provided at any frequency (Smith, 1969). Furthermore, the protective capacity of hoods is essentially eliminated if only small additional areas (two square inches) of the head are exposed to the water (Montague and Strickland, 1961). Rigorous evaluation of wet suit hoods as ear defenders has yet to be accomplished. Nevertheless, as a minimum precaution, wet-suited divers exposed to noise in water should wear hoods.

The nonauditory symptoms reported by the divers are also disturbing. They raise questions concerning the ability of wet-suited divers to work effectively and safely under such conditions. Some commercial divers have complained of being dizzy after using water-jet tools (Molvaer and Gjestland, 1981). The extent to which accidents that may have occurred while divers were using hand-held tools are attributable to the attendant noise is not known. Hoods seem to provide some protection from certain nonauditory effects ((Montague and Strickland, 1961), but the degree of protection may be only about 10 dB.

Also, of course, the ear-drum damage observed in diver D indicates that medical consequences other than hearing loss are likely to accompany exposure to intense sound in water. There is every reason to suspect that any gas/tissue interface or any site at which a significant change in the acoustic impedance between tissues exists within the body could be similarly affected (Smith and Hunter, 1979).

That these subjects reported nonauditory effects usually associated with exposure to sound in air at 120 to 140 dB suggests that the dynamic range of the water-immersed ear is smaller than that of the ear in air. Montague and Strickland's data seem to indicate that the dynamic range of the water-immersed ear may be as small as 100 dB at 1500 Hz. There is a protective mechanism in the middle ear (the acoustic reflex) which reduces the transmission of sound from the ear canal to the cochlea at high air-borne sound levels thereby extending somewhat the dynamic range of the ear. Since hearing in water at the frequencies used in this experiment is most likely bone-conduction hearing, then the middle ear may be effectively bypassed. The acoustic reflex may be activated by intense noise in water but, since the middle ear is out of the conduction path, the reflex is ineffective. However, the middle-ear reflex is least protective at the frequencies above 1000 to 2000 Hz and is only unreliably activated by pure tones and hence may be of little relevance to the present results.

Regardless of what mechanism accounts for the reduced dynamic range of the water-immersed ear, one could expect that

beyond a sensation level of about 85 to 90 dB (85 to 90 dB above threshold level, the level beyond which the air-immersed ear becomes nonlinear), the water-immersed ear is much more vulnerable to insult than is the ear in air. The method recently proposed as an interim standard for assessing noise hazards in water using equal sensory magnitudes (Smith, 1983) ought therefore to be considered invalid for sensory magnitudes in excess of 85 dB.

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Footnote

1. In this paper, all sound pressure levels (SPL) are with reference to 20 micropascals.

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		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Noise exposure, Hyperbaric environments, Hearing conservation

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Four bare-headed divers were exposed for twenty-five minutes to continuous tones in water at frequencies of 700, 1400, and 5600 hertz at estimated sound pressure levels between 153 and 165 decibels (dB) above 20 micropascal. Subsequent analyses revealed that the eight ears involved were actually exposed to average sound pressure levels between 143.1 and 165.1 dB. These exposure levels are comparable to those to which divers may be exposed while using some underwater hand-held tools. Temporary auditory-threshold shifts (TTS) were measured from

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two minutes to five minutes after the exposure terminated. TTS at two minutes post-exposure was between 23 and 55 dB and recovery times varied from twenty-four hours to more than fifty hours depending on exposure conditions. Non-auditory effects including middle-ear sensations and a reddened ear-drum were also observed. The results indicate that several hand-held tools now in use by military and civilian divers are extremely hazardous to hearing. The results also support the theory that the dynamic range of the water-immersed ear is smaller than the dynamic range of the ear in air.